Mediterranean desert dust outbreaks' direct impact on the radiation budget

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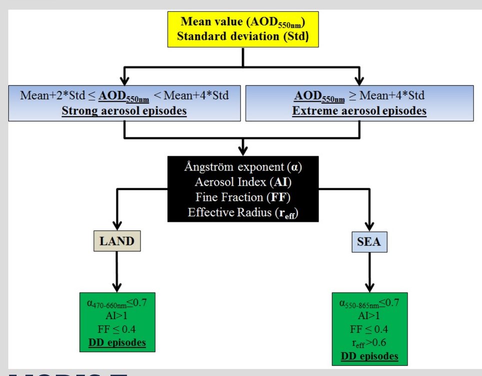
Estimation of the direct radiative effect (DRE), through NMMB/BSC - Dust model simulations, induced by 20 Mediterranean desert dust outbreaks, which have been identified based on an objective and dynamic alrgorithm using as inputs daily retrievals derived by MODIS-Terra, EP-TOMS and OMI-Aura satellite databases.

Dust episodes



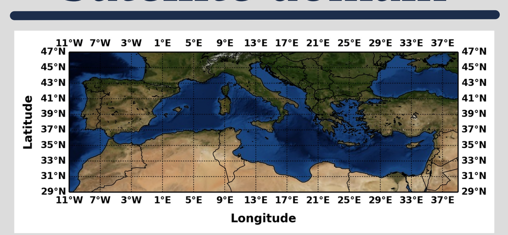
MODIS-Terra
- AOD at 550nm (Land and Sea)
- Ångström exponent (Land and Sea)
- Fine Fraction (Land and Sea)
- Effective radius (Sea)

EP-TOMS & OMI-Aura
- Aerosol Index (Land and Sea)

Satellite data

Study period: 1 March 2000 - 28 February 2013
Satellite domain: 11° W - 39° E, 29° N - 47° N
Satellite sensors: MODIS-Terra/Aqua (C051, C006), Earth Probe - TOMS, OMI - Aura
Temporal resolution: Daily retrievals
Spatial resolution: 1° x 1°

Satellite domain



Selection of desert dust outbreaks

Desert dust (DD) episodes are identified in each 1° x 1° geographical cell of the Mediterranean domain based on an objective and dynamic algorithm, which is depicted in the flowchart (Gkikas et al., 2013). According to its outputs, for each day over the period 1/3/2000-28/2/2013 it is calculated the number of grid cells in which a DD episode has been recorded. Then, the days where the overall number of DD episodes is lower than 30 (Gkikas et al., 2014) are masked out. The remaining days are sorted based on their mean regional AOD_{550nm} considering also which Mediterranean subregions are affected. The final dataset (20 desert dust outbreaks) is listed in the following table.

Dates	Affected Mediterranean parts
31 July 2001	Western
8 May 2002	Central
4 April 2003	Eastern
16 July 2003	Western and Central
22 February 2004	Central and Eastern
26 March 2004	Central and Eastern
27 January 2005	Central and Eastern
2 March 2005	Central and Eastern
28 July 2005	Western and Central
24 February 2006	Eastern
19 March 2006	Central and Eastern
24 February 2007	Eastern
21 April 2007	Central
29 May 2007	Eastern
10 April 2008	Central
19 May 2008	Central
23 January 2009	Eastern
6 March 2009	Eastern
27 March 2010	Central
2 August 2012	Western

NMMB/BSC - Dust model

- NMMB/BSC-Dust model contains a dust module embedded online within the NCEP Non-hydrostatic Multiscale Model (NMMB).
- Provides weather and dust forecasts, from regional to global scales, thanks to its unified non-hydrostatic dynamical core.
- Dust cycle is represented through several parameterizations describing dust particles' sources, emissions, transport, removal from the atmosphere (wet and dry deposition) as well as the interaction with the radiation (Pérez et al., 2011).
- After a 10-day spin-up period, model outputs every three hours for a 168h (7 days) forecasting period are selected.
- Forecast period starts at 00:00 UTC of each day where a dust outbreak has been identified by satellite observations.
- NCEP final analyses (FNL) initial and boundary conditions at 1° x 1° are used.
- The simulation domain covers the largest part of Europe as well as the northern African and Arabian Peninsula deserts, at 0.25° x 0.25° spatial resolution and for 40 hybrid sigma pressure levels up to 50hPa.

Direct Radiative Effect

The direct radiative effects (DREs) in the Earth-Atmosphere system are calculated based on the following formulas:

1. Top of Atmosphere (**TOA**)

$$DRE_{TOA} = F^{\uparrow}_{TOA,RADOFF} - F^{\uparrow}_{TOA,RADON}$$

2. Into the Atmosphere (**ATMAB**)

$$DRE_{ATMAB} = F_{ATMAB,RADON} - F_{ATMAB,RADOFF}$$

3. Downwelling radiation at surface (**SURF**)

$$DRE_{SURF} = F^{\downarrow}_{SURF,RADON} - F^{\downarrow}_{SURF,RADOFF}$$

4. Absorbed radiation at surface (**NETSURF**)

$$DRE_{NETSURF} = F_{NETSURF,RADON} - F_{NETSURF,RADOFF}$$

RADON: dust-radiation interaction
RADOFF: no dust-radiation interaction

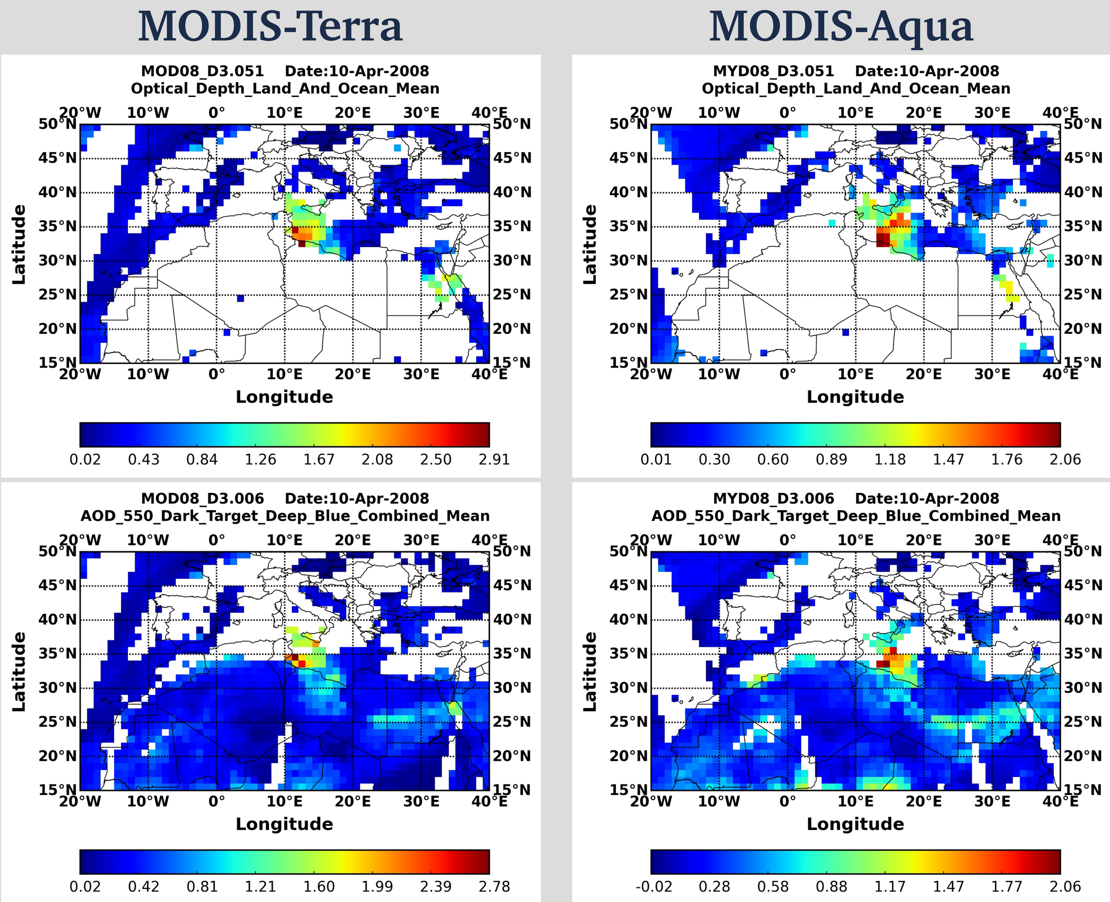
Positive DREs indicate **warming** while **negative** DREs indicate **cooling**.

Results

Satellite observations (10 April 2008)

MODIS-Terra | MODIS-Aqua

Collection 051 | Collection 006

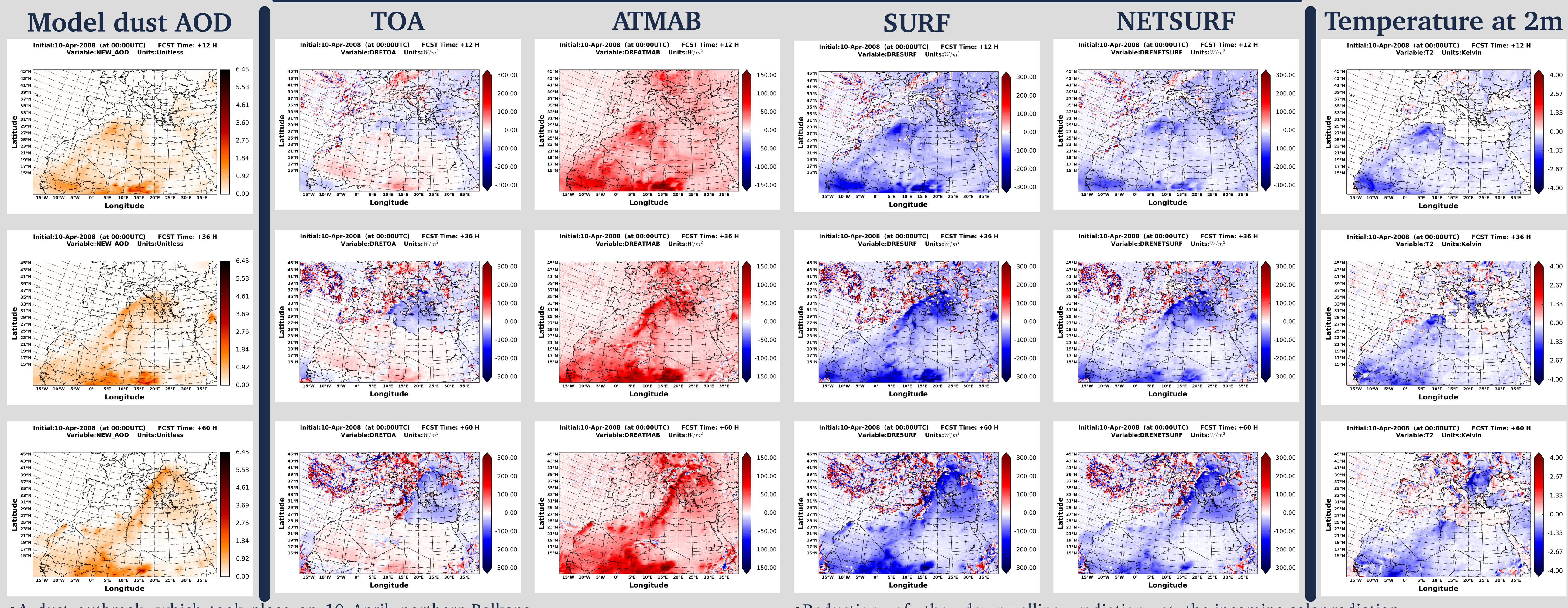


- Geographical distributions of aerosol optical depth (AOD) at 550nm, on 10 April 2008, derived by MODIS-Terra and MODIS-Aqua satellite sensors (Level 3, 1° x 1°).
- Dark Target (DT) and Deep Blue (DB) retrieval algorithms.
- Collection 051 (C051) and Collection 006 (C006) where DT (deserts are not included) and DT+DB retrieval algorithms are applied, respectively.
- The desert dust outbreak is identified over the Gulf of Gabes.
- AODs reach up to 2.9 based on MODIS-Terra C051 retrievals.
- High AODs (up to 1.3) are recorded in the northern parts of Libya.
- Lower AODs and a slight eastward shift of the dust plume are found based on MODIS-Aqua observations.

DREs

Model dust AOD | TOA | ATMAB | SURF | NETSURF | Temperature at 2m

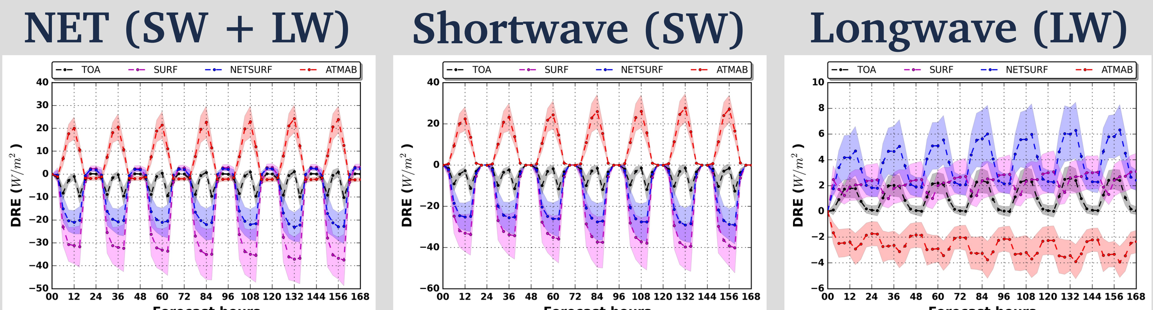
+ 12 H | + 36 H | + 60 H



- A dust outbreak, which took place on 10 April 2008, affected mainly the central parts of the Mediterranean basin.
- Dust outbreak originated in the northern parts of Algeria (+12H) with AODs up to 1.5, based on NMMB simulations.
- In the second day (+36H), the dust plume affected Italy and Balkans.
- At +60H, the dust plume is shifted eastwards, becoming narrower, and its range extended up to northern Balkans.
- Both DREs' magnitude and spatial patterns are driven by the dust aerosol optical depth.
- Negative DRE_{TOA} values (cooling effect) up to 250 Wm^{-2} are found over seas and low albedo land surfaces.
- Slight positive DRE_{TOA} values (warming effect) up to 50 Wm^{-2} are found over desert areas.
- Strong atmospheric warming across the dust plume (DRE_{ATMAB} values up to 150 Wm^{-2}).
- Reduction of the downwelling radiation at surface results in a strong surface cooling (DRE_{SURF} values down to -300 Wm^{-2}).
- Similar effects but lower DREs are calculated for the NETSURF.
- Reverse effects of lower magnitude are observed during nighttime.
- Temperature at 2 meters is decreased by up to 4° C during daytime due to the attenuation (scattering and absorption by dust aerosols) of the incoming solar radiation.
- During nighttime, temperature at 2 meters can be increased by up to 3° C attributed to the absorption and re-emission of LW radiation by dust aerosols.
- The combination of reduction/increase of temperature at 2 meters during day/night results in a reduction of the diurnal temperature range.

Regional DREs

NET (SW + LW) | Shortwave (SW) | Longwave (LW)

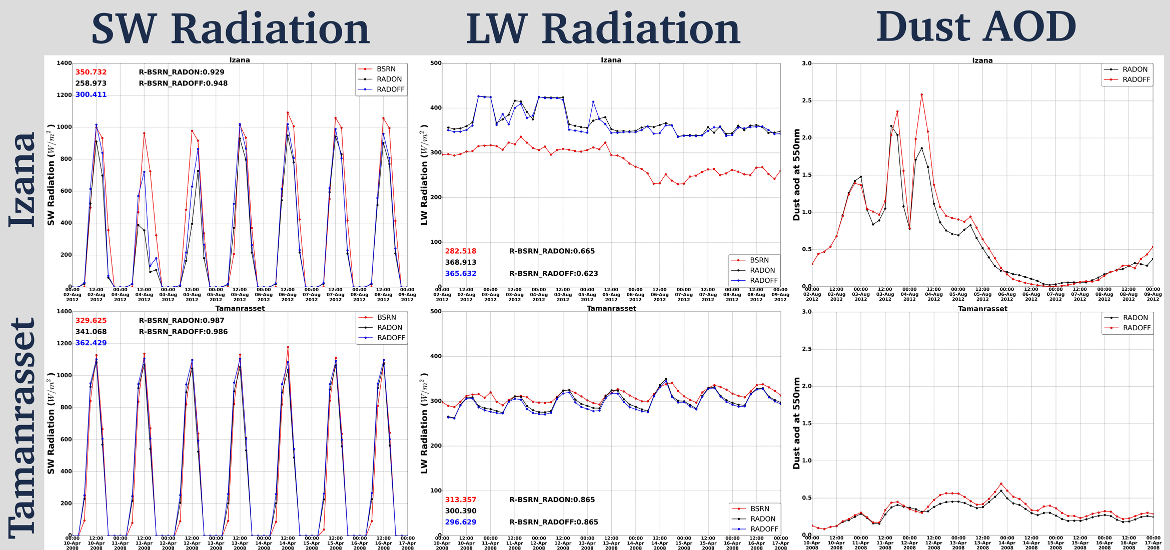


- Regional DREs for NET, SW and LW radiation, under clear skies conditions, averaged over the whole simulation domain.
- Atmospheric warming and surface cooling for the SW radiation and during daytime.
- Opposite but less pronounced effects are found for the LW radiation and during nighttime.
- Slightly positive NET TOA DREs can be found at 12UTC indicating warming of the Earth-Atmosphere system.
- **TOA:** Negative (down to -15 Wm^{-2}) and positive (up to 3 Wm^{-2}) DREs for the SW and LW radiation, respectively.
- **ATMAB:** Positive (up to 30 Wm^{-2}) and negative (down to -4 Wm^{-2}) DREs for the SW and LW radiation, respectively.
- **NETSURF:** Negative (down to 30 Wm^{-2}) and positive (up to 6 Wm^{-2}) DREs for the SW and LW radiation, respectively.
- **SURF:** Similar effects but higher DREs compared to NETSURF ones.

NMMB vs BSRN Radiation

SW Radiation | LW Radiation | Dust AOD

Izana | Tamanrasset

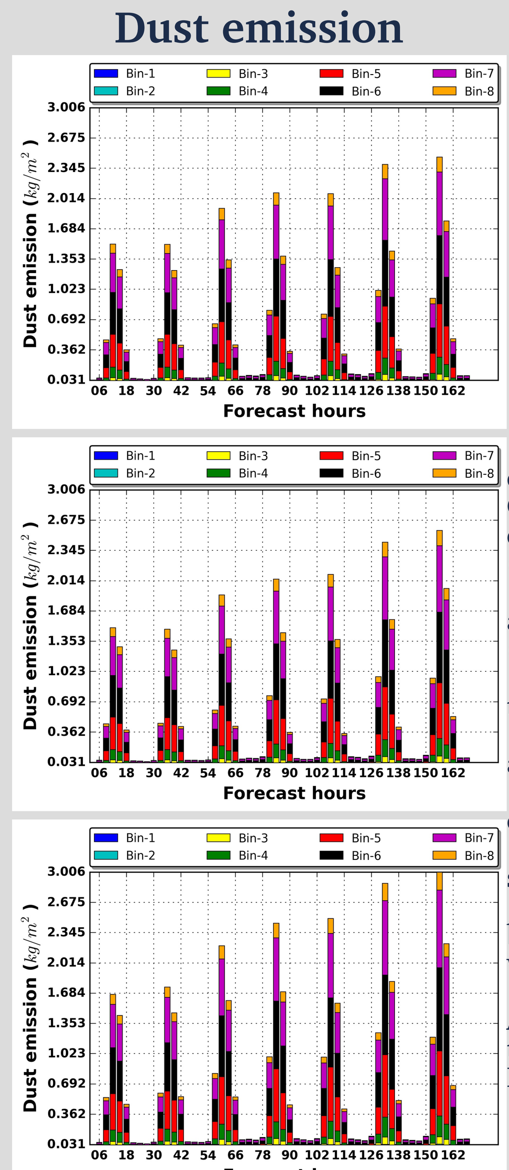


- Comparison of the NMMB downward SW and LW radiation at the surface against Baseline Surface Radiation Network (BSRN; Ohmura et al., 1998) measurements.
- Izana (2 August 2012, Canary Islands) and Tamanrasset (10 April 2008, Algeria).
- Very good agreement (R up to 0.987) between NMMB-BSRN SW radiation.
- Overestimations of the NMMB LW radiation vary from 50 to 100 Wm^{-2} in Izana.
- Better agreement for the LW radiation between NMMB-BSRN in terms of biases (less than 30 Wm^{-2}) and correlation coefficients (R=0.865) in Tamanrasset.
- NMMB-BSRN discrepancies are attributed primarily to false clouds reproduction and secondarily to overestimated AODs by the model.

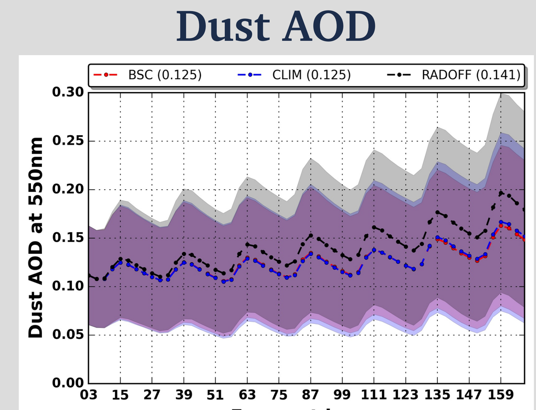
Feedbacks

Dust emission

BSC | CLIM | RADOFF



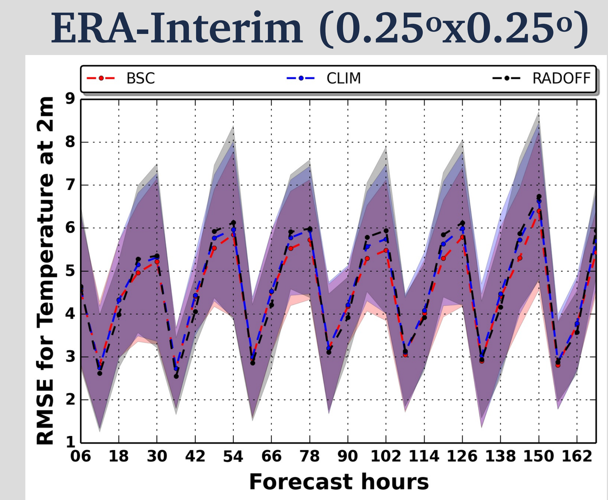
Dust AOD



- Three NMMB configurations: (i) dust is dynamically calculated and interacts with the radiation (BSC), (ii) GOCART dust climatology (year 2000) is used and dust-radiation interaction is activated (CLIM) and (iii) no dust-radiation interaction (RADOFF).
- 8 bins (r_{eff}=0.15, 0.25, 0.45, 0.78, 1.32, 2.24, 3.80 and 7.11 μm) in the model's emission scheme (Haustein et al., 2012).
- Dust emissions are maximized during midday while their major portion comes from bins 5, 6 and 7.
- Dust emissions are lower for BSC compared to CLIM and even lower compared to RADOFF.
- Negative feedback on dust emissions when radiative effects are considered in the numerical simulations.
- Higher mean regional dust AODs for the RADOFF simulations.
- The positive differences of dust AOD at 550nm between RADOFF-RADON simulations are increasing with forecast time.
- Based on NMMB outputs, the mean regional dust AODs at 550nm, over the forecast period, are equal to 0.125, 0.125 and 0.141 for BSC, CLIM and RADOFF simulations, respectively.

Forecasting efficiency

ERA-Interim (0.25°x0.25°)



- Root Mean Square Error (RMSE) between NMMB and ERA-Interim for temperature at 2 meters.
- Selection of grid points where dust AOD is higher than 0.5.
- Lower RMSEs (at around 3) during midday where maximum temperatures are recorded.
- Higher RMSEs (ranging from 5 to 7) during nighttime where minimum temperatures are recorded.
- Decreasing RMSEs during nighttime, when dust radiative effects are considered in the simulations, indicating a better ability of the model to reproduce the minimum temperatures.

Conclusions

- Estimation of the DRE induced by 20 Mediterranean desert dust outbreaks which have been identified by satellite observations.
- At a local scale, during midday, for the net radiation, it is estimated an instantaneous planetary and surface cooling by up to 250 Wm^{-2} and 300 Wm^{-2}, respectively, and an atmospheric warming by up 150 Wm^{-2}. (case of 10 April 2008)
- On a mean regional scale (simulation domain), the net DRE_{TOA}, DRE_{ATMAB}, $DRE_{NETSURF}$ and DRE_{SURF} can reach up to -15 Wm^{-2}, 30 Wm^{-2}, -30 Wm^{-2} and -40 Wm^{-2}, respectively, under clear skies conditions.
- Reverse but substantially lower DREs are found during nighttime and for the LW radiation.
- In the dust affected areas, the temperature at 2 meters can be decreased by 4° C during midday while an increase of the same magnitude is recorded during nighttime. (case of 10 April 2008)
- Negative feedbacks on dust emissions and mean regional dust AOD are found when dust radiative effects are considered in the simulations.
- The evaluation of the NMMB against BSRN for the downward radiation at the ground, reveals that the model is able to reproduce better the SW than the LW.
- NMMB-BSRN discrepancies are attributed primarily to false clouds reproduction and secondarily to overestimated AODs by the model.
- The consideration of dust radiative effects improves the ability of the model to reproduce the minimum temperatures.

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